N91-14396

LOW DARK CURRENT PHOTOVOLTAIC MULTIQUANTUM WELL LONG WAVELENGTH INFRARED DETECTORS

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We have, for the first time, demonstrated photovoltaic detection for an multiple quantum well (MQW) detector. With a blocking layer, the MQW detector exhibits Schottky I-V characteristics with extremely low dark current and excellent ideality factor. The dark current is 5×10^{-14} A for an 100x100 um^2 10 um detector at 40 K, 8-9 orders of magnitude lower than that of a similar 10 um MQW detector without blocking layer. The ideality factor is ~1.01-1.05 at T=40-80 K. The measured barrier height is consistent with the energy difference between first excited states and ground states, or the peak of spectral response. We also, for the first time, report the measured effective Richardson constant (A**) for the GaAs/AlGaAs heterojunction using this blocking layer structure. The A** is low ~2.3 $A/cm^2/K^2$.

GaAs-BASED MULTIQUANTUM WELL LONG WAVELENGTH INFRARED DETECTOR

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GaAs MQW SL DETECTOR OUTLINE

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- ADVANTAGES
- CONVENTIONAL VS HUGHES MQW
- MQW DETECTOR DESIGN
- TEST RESULTS
  - -LOW DARK CURRENT OPERATION
  - -PHOTOVOLTAIC DETECTION
- SUMMARY

ADVANTAGES OF MQW SUPERLATTICE LWIR DETECTOR

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- BUILT-IN FILTER CHARACTERISTICS
- DESIGN FLEXIBILITY IN SPECTRAL RESPONSE
- RADIATION HARDNESS POTENTIAL
- POTENTIALLY EXCELLENT UNIFORMITY FROM PIXEL TO PIXEL
- COMPATIBLE WITH STANDARD GaAs IC PROCESSING TECHNOLOGY

MULTIPLE QUANTUM WELL DETECTOR OPERATION

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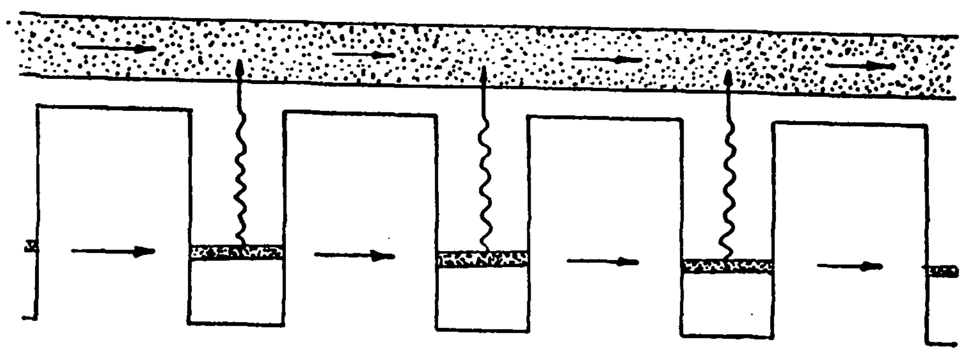

$I_{TOT} = I_{PH} + I_{TUN}$

DESIGN FLEXIBILITY

MQW DETECTOR WITH TUNNELING CURRENT BLOCKING LAYER

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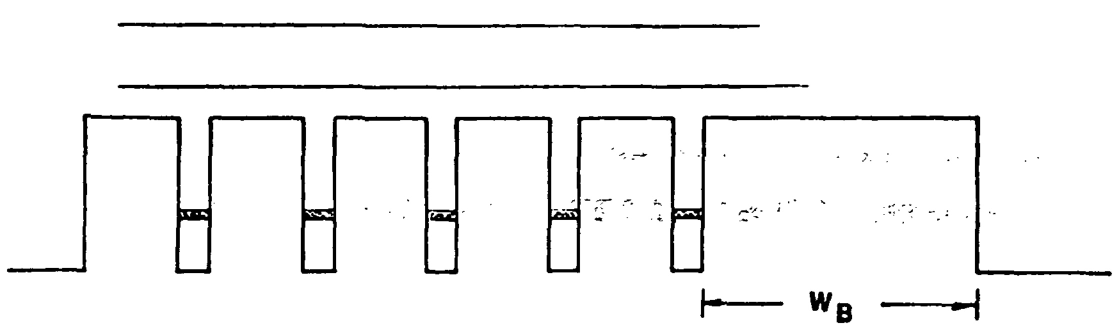

$I_{TUN} \sim \exp(-2KW_B)$

BLOCKING LAYER RESULTS IN LOW DETECTOR DARK CURRENT, IMPROVED SNR AND REDUCED PRIME POWER CONSUMPTION

DETECTOR PERFORMANCE SIMULATION - MQW PARAMETER DEFINITION

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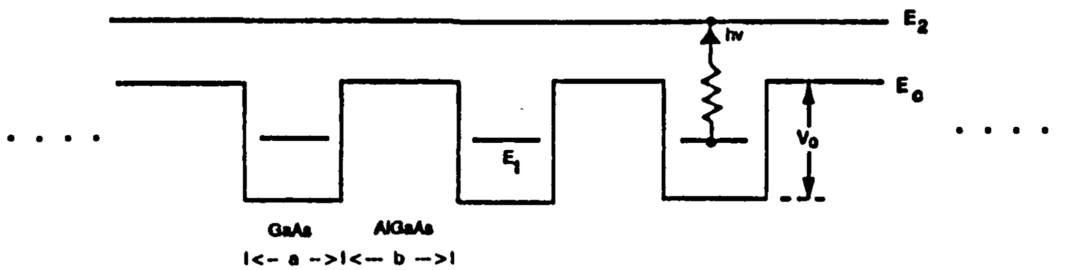
A PERIODIC POTENTIAL WITH RECTANGULAR SECTIONS
(PERIOD LENGTH = a + b)



SCHRODINGER EQUATION FOR KRONIG-PENNEY POTENTIAL:

$$-\frac{\hbar^2}{2M^*}\frac{d^2\psi(x)}{dx^2} + V(x)\psi(x) = E\psi(x)$$

(two unknowns: $\psi(x)$ (wave function) and E (electron energy))

where $V(x)$ and $\psi(x)$ satisfy

PERIODICITY CONDITIONS:
$V(x) = V(x+a+b)$ and

therefore $\psi(x+a+b) = e^{i\phi}\psi(x)$ ($e^{i\phi}$: real)

MQW IR DETECTOR DESIGN CONSIDERATIONS

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* **SPECTRAL RESPONSE**
  - **WELL WIDTH, BARRIER HEIGHT, BARRIER THICKNESS**
* **ACTIVE REGION THICKNESS**
  - **CARRIER DENSITY, BARRIER THICKNESS**
* **CARRIER MEAN FREE PATH**
  - **MOBILITY, BIAS CONDITION, CARRIER LIFE TIME**
* **DARK CURRENT**
  - **BARRIER THICKNESS, BARRIER HEIGHT**
  - **BLOCKING LAYER (THICKNESS, HEIGHT)**

GaAs/AlGaAs MQW DETECTOR ARRAYS DESIGN

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* DESIGNED FOR $\lambda \approx$ 10 MICRONS
* BLOCKING LAYER FOR LOW DARK CURRENT
  - LOW BACKGROUND OPERATION
* 4 X 4 ARRAYS
  - 100μM X 100μM DETECTORS
  - 40μM X 40μM DETECTORS
* THIN DETECTOR STRUCTURE TO ENHANCE RADIATION HARDNESS
* STANDARD GaAs IC PRODUCTION LINE FABRICATION TECHNOLOGY

4 x 4 PHOTO DETECTOR ARRAYS

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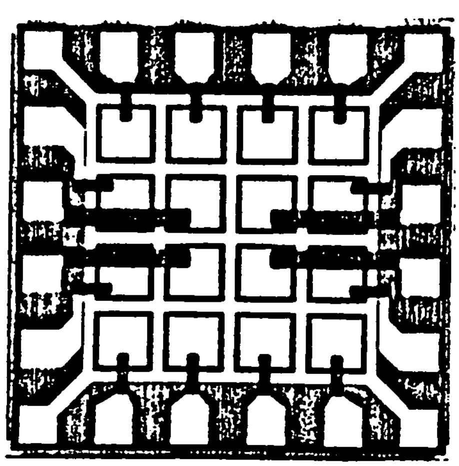
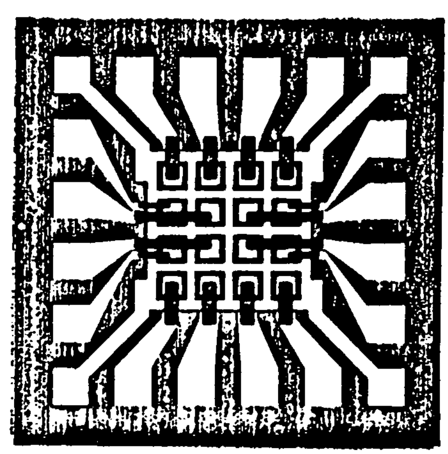
DETECTOR SIZE 100 x 100 uM



40 x 40 uM



DARK I-V CHARACTERISTICS

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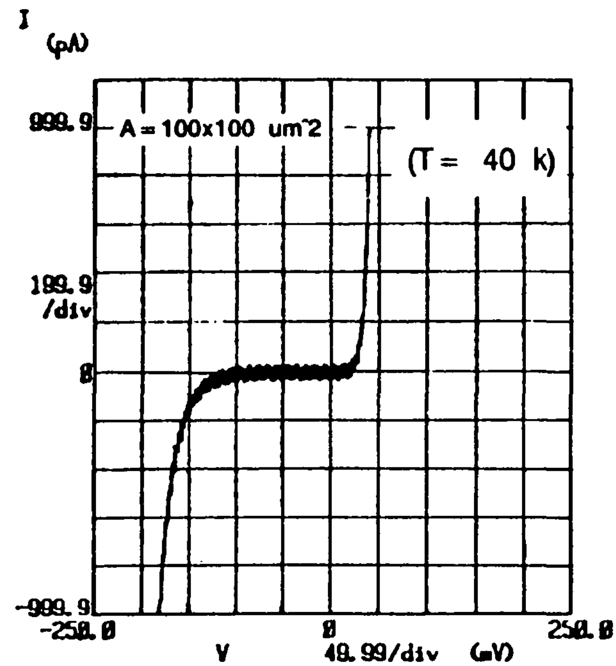

MQW SL DETECTOR STRUCTURE WITH BLOCKING LAYER - QUANTUM WELL " SCHOTTKY " JUNCTION

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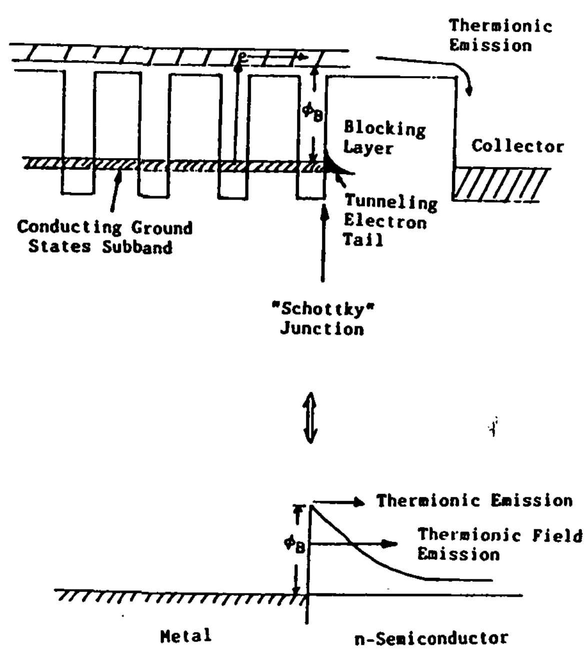

- PHOTOVOLTAIC DETECTION LIKE PtSi DETECTOR
- LOW DARK CURRENT & HIGH RoA (NO THERMIONIC FIELD EMISSION)
- SELECTIVE SPECTRAL RESPONSE (ADJUSTABLE "ϕB")

SCHOTTKY DIODE'S EQUATION

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$$J = J_S(e^{qV/nkT} - 1)$$

$$J_S = A^{**}T^2 \exp\left(-\frac{q\phi_B}{kT}\right)$$

ϕ_B Schottky barrier height

A^{**} effective Richardson constant

n ideality factor

MEASUREMENT OF SCHOTTKY BARRIER HEIGHT, IDEALITY FACTOR & RICHARDSON CONSTANT

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(A) $\ln I_F$ versus V_F -----> solve for n & ϕ_B

$$\ln I_F = \ln I_S + \frac{qV_F}{nkT}$$

(B) $\ln(I_F/T^2)$ versus $1/T$ (ACTIVATION ENERGY PLOT)

------> solve for ϕ_B & A^{**}

$$\ln(I_F/T^2) = \ln(A\,A^{**}) - q(\phi_B - V_F)/kT$$

FORWARD DARK I-V CHARACTERISTICS

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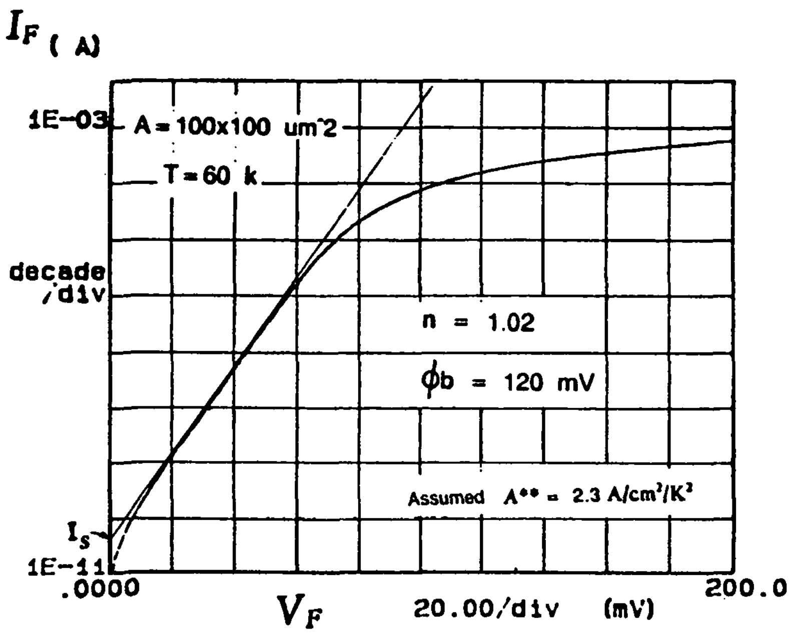

$$n = \frac{q}{kT}\frac{\partial V}{\partial(\ln J)}$$

$$\phi_B = \frac{kT}{q}\ln\left(\frac{A^{**}T^2}{J_S}\right)$$

FORWARD I-V CHARACTERISTICS
AT T = 30 TO 80 K

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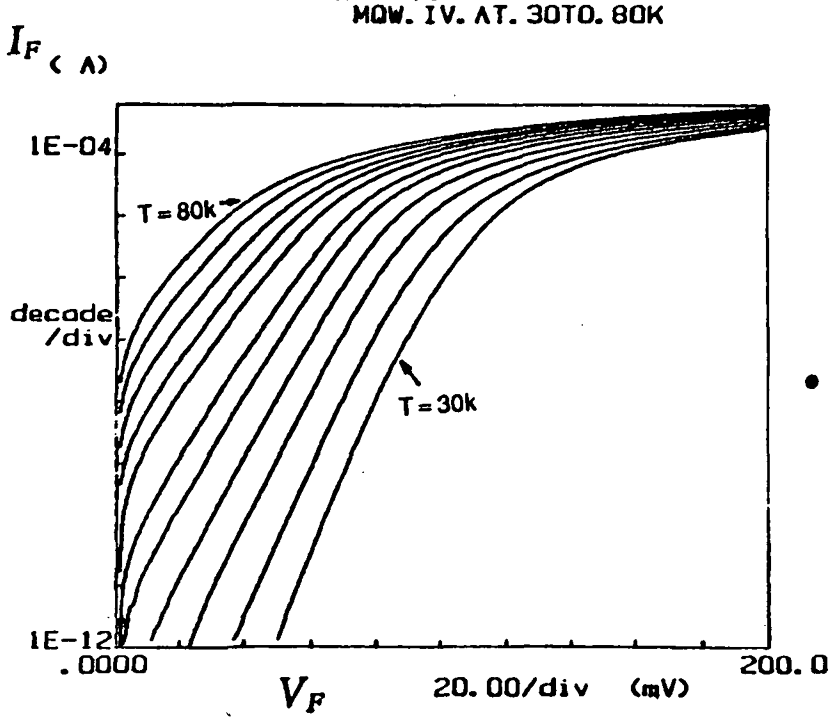
****** GRAPHICS PLOT ******
MQW. IV. AT. 30TO. 80K



Variable1:
V2 -Ch2
Linear sweep
Start .0010V
Stop .2000V
Step .0010V

Constants:
V1 -Ch1 .0000V

- EXTREMELY LOW PARASITIC LEAKAGE CURRENT

SCHOTTKY BARRIER HEIGHT AND RICHARDSON CONSTANT OBTAINED FROM ACTIVATION ENERGY PLOT

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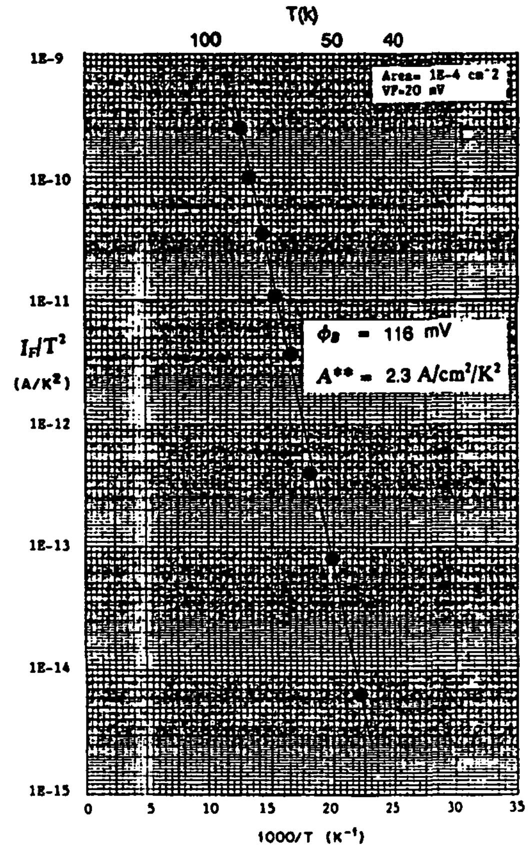

DARK CURRENT VS TEMPERATURE FOR 10 um PHOTOVOLTAIC MQW DETECTOR

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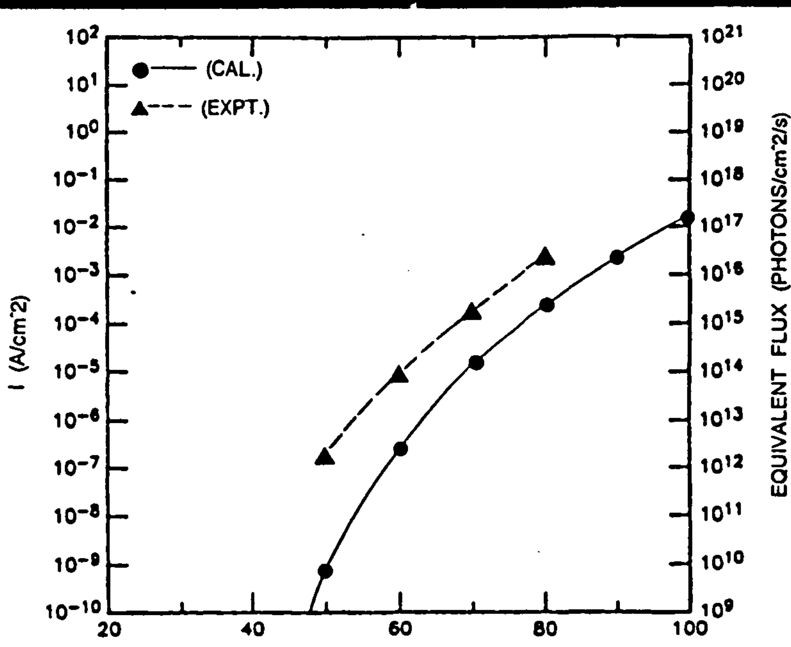

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GaAs Based MQW IR Detector
Dark Current Characterization

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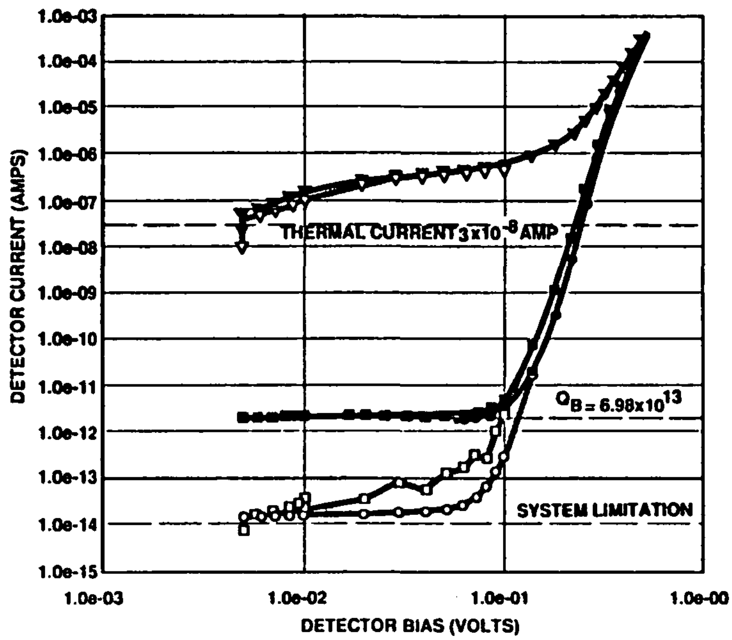

9002-01 W#01 (001) 08-2
CABLING NO. : 0001
DET TYPE : ALGAAS MQW
DET AREA : 1.00E-04 cm^2

DATE/OPERATOR/STATION:

5 - SEPT - 1989 17:25:01
CLAY
DRAD 01
DATA FILENAME :
[DARC.9002.z.01]
01 001 011.r001

TEMP	FLUX
10.000	< 1E+8
10.000	6.98E+13
40.000	< 1E+8
40.000	6.98E+13
80.000	< 1E+8
80.000	6.98E+13

GaAs/AlGaAs MQW IR DETECTOR
PHOTOVOLTAIC IR DETECTION
I - V CURVE

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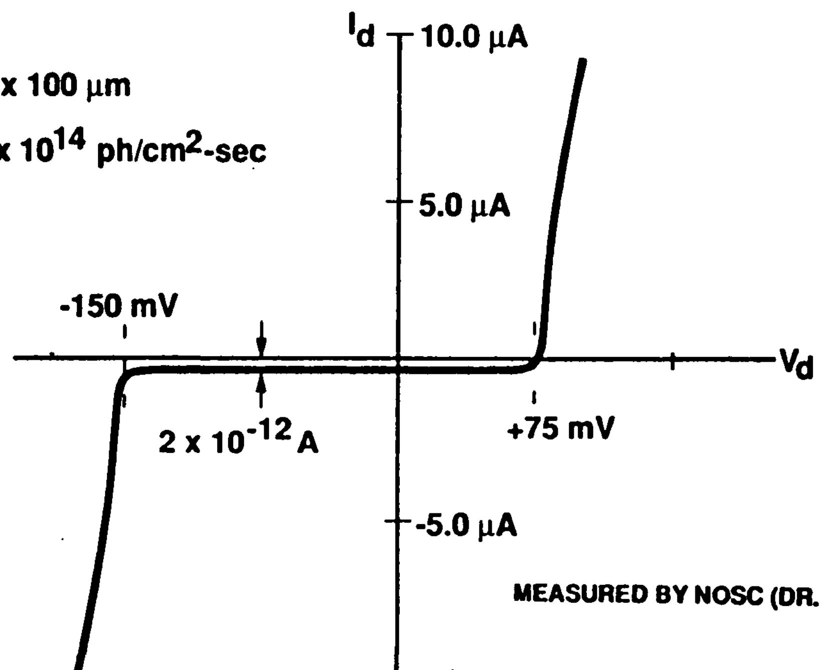
$A_d = 100 \times 100\ \mu m$

$Q_B = 3.9 \times 10^{14}$ ph/cm^2-sec

T = 10°K



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MEASURED BY NOSC (DR. FLESNER)

GaAs/AlGaAs MQW IR DETECTOR NORMALIZED SPECTRAL RESPONSE $T = 10° K \quad Q_B = 3.9 \times 10^{14}$

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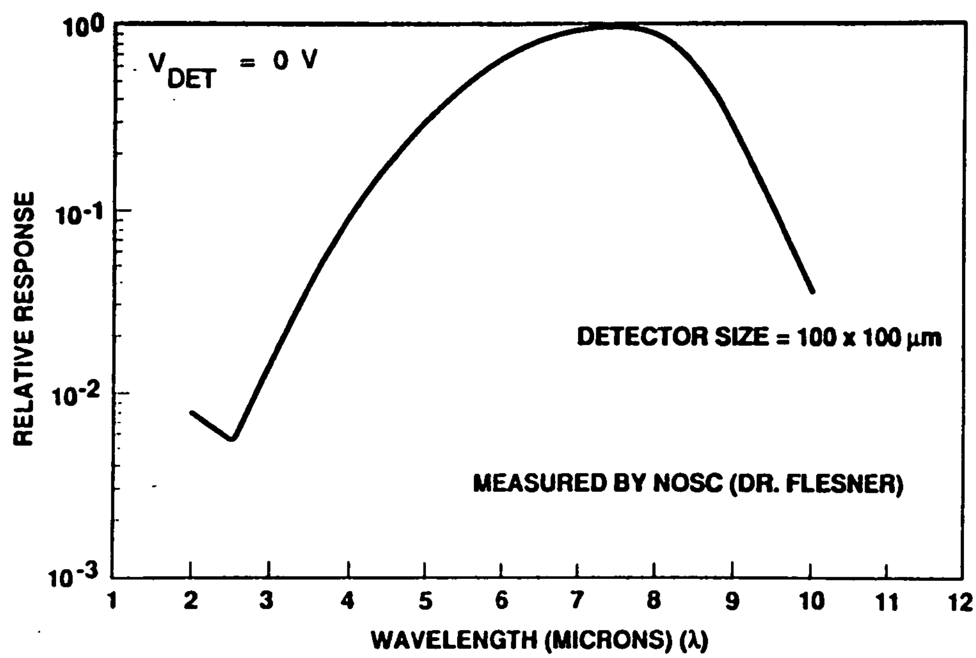

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SUMMARY

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- GaAs MQW LW IR DETECTORS DEMONSTRATED
  - -LOW DARK CURRENT
  - -POTENTIAL LOW NOISE
  - -PHOTOVOLTAIC DETECTION (LOW DETECTOR BIAS REQUIRED)
  - -POTENTIAL RADIATION HARDNESS
  - -EXCELLENT DESIGN FLEXIBILITY
    PEAK PHOTO RESPONSE BANDWIDTH
- GaAs IC PRODUCTION TECHNOLOGY COMPATIBLE
  - -MATURED TECHNOLOGY
  - -HIGH YIELD, GOOD UNIFORMITY